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THE LOESS SOILS OF THE NEBRASKA PORTION OF THE TRANSITION REGION:

I. HYGROSCOPICITY, NITROGEN AND ORGANIC CARBON.[1]

By

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INTRODUCTION.

"The sloping plains country lying between the Rocky Mountains and the Mississippi, quite arid at the foot of the mountains, but with rainfall increasing more or less regularly to eastward, forms a transition-belt between the arid and the humid region of which but a small portion[3] has been systematically studied with respect to its soil formation" (18—*Hilgard,* Soils, p. 397).

In this *transition region* no other surface formation seems to offer such an opportunity for the study of the relation of the properties of its soils to the climate as does the large area indicated in Fig. 1 as derived from wind-laid material and commonly referred to as *loess.* The soils of about half of Nebraska are derived from this deposit and the agricultural importance of these far exceeds that of all the other soil areas combined. The Dune Sands which occupy most of the north-central portion of the state are devoted almost exclusively to pasturage. Residual soils, while extensively developed, are almost entirely confined to the distinctly semi-arid western portion of the state. Glacial soils occupy a considerable portion of the southeastern part of the state, but much of their area is too

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[1] Received for publication February 10, 1916.

[2] The work reported in this paper was carried out at the Nebraska Agricultural Experiment Station, where the authors were Chemist and Research Assistant in Chemistry, respectively.

[3] This "small portion" refers to parts of Minnesota and North Dakota.

rough for satisfactory tillage and hence their agricultural importance does not correspond to their acreage. The loess, on the contrary, although in a few places too badly dissected to permit of cultivation, in general forms level plains or comparatively gentle slopes, ideal for tillage, and only a small part of it lies so far to the west as to be very seriously affected by a lack of sufficient rainfall. All of these factors combine to give the loess soils the most prominent place in the study of Nebraska agriculture.

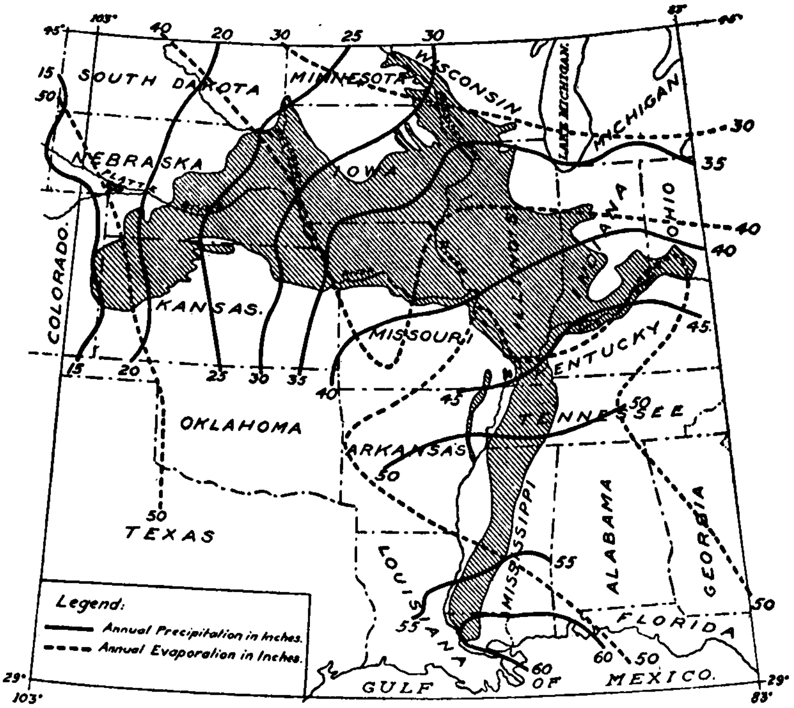

Fig. 1.—Map showing distribution of loess[1] in the United States and also the annual precipitation[2] and evaporation[3] of the loess region. ([1]From map by G. N. Coffey, to accompany Bul. 85, Bur. Soils, U. S. Dept. Agr., 1912, and map of Reconnoissance Survey of Western Nebraska, Bur. Soils, 1913. [2]Climatology of U. S., Plate xxvi, 1906. [3]Monthly Weather Review, 1904, fig. 1, p 558.)

Uniformity in physical properties has long been recognized as characteristic of the loess, but previous to the studies partly reported in the present article little attention had been paid to the chemical composition of the Nebraska portion.

Within only recent years has it come to be recognized, first through the work of Hilgard in the United States, and later through the work of Dokutschajew and Sibertzew in Russia, that in general the character of the soil is much more dependent upon the climate of the region in which it is found than upon the character of the rock from which it has been derived, or upon the manner of its formation. Thus a granite may weather to produce a soil very similar to that developed upon a wind-laid silt loam or a lacustral clay when all three have been exposed for a sufficient length of time to the same climate, while all will be quite distinct in character from the soils that would have resulted under a radically different climate.

According to climate soils are classified as those of *humid regions*, in which the precipitation exceeds the evaporation, and those of *arid regions*, in which the precipitation is less than the evaporation from a water surface (23, p. 523). It is difficult to define sharply the limits for either class. In addition to the amount of the annual precipitation it is necessary to take into consideration its distribution as well as the temperature, the relative humidity of the air, the wind movement and the intensity of the solar radiation. Accordingly, the usual meteorological data do not give us definite information as to the class to which the soils of a region belong. A much better criterion is the amount of percolation which the soil suffers; if the seepage is considerable it is under humid conditions.

The Committee, of the American Society of Agronomy, on Soil Classification and Mapping has recently proposed to recognize a third division to embrace the soils of the *semi-arid* regions (13, p. 285).

The uniformity in physical properties, recognized as characterizing the material of the loess, should tend to produce, under uniform climatic conditions, soils uniform in chemical properties. The importance of working with soils of similar texture in a study of the relation of their chemical composition to climate is evident, as the most marked effect of a heavy precipitation is the leaching out of the soluble salts and the carbonates. A precipitation, too light to cause the water to penetrate beyond the reach of the plant roots in the case of a fine-textured soil, may regularly cause percolation in an adjacent sand, the water-holding capacity of the latter being much lower. There would thus be developed in the former the characteristics of an arid, and in the latter those of a humid soil, although the two types may be adjacent.

The residual soils immediately to the west and northwest, where similar in water capacity, may be expected to resemble those of the adjacent loess. Likewise, the glacial soils of the southeastern part of the state are likely to show many of the characteristics of the loess around Lincoln and Weeping Water.

The mode of deposition of this æolian deposit makes it highly probable that the portion of it now constituting the soil and subsoil was originally very uniform in chemical composition, at least within the limits of different districts, even though it may have shown great variations between distant parts, as when that in Ohio is compared with that in eastern Colorado.

Our study of the loess has been confined entirely to the Nebraska portion, which offers exceptional advantages, the humidity decreasing steadily from the Missouri to its western limit. The formation covers the hills and valleys alike to a depth of from 20 to 100 feet, being much thicker than this in some places and much thinner in others. Throughout the first hundred miles westward from the Missouri it is underlain by Kansan till, while throughout the remainder of the distance it overlies Cretaceous and Tertiary formation (7, p. 169; 14).

The dark-colored prairie soils which occupy the Nebraska portion of the loess have been recognized as similar to the Russian Chernozem (black earth). The chief labors of Russian soil investigators have been devoted to the Chernozem and they emphasize the paucity of data on similar soils in the United States. Thus Kossowitsch (20, p. 338-339) makes the following statements:

> "Concerning the Chernozem soils of North America as such we know very little; the American soils investigators, in so far as we know, actually even do not recognize any special soil type which would be analogous to the Russian Chernozem soils. The zone . . . . . of the Chernozem extends approximately through the states of North and South Dakota, Nebraska, Kansas, Oklahoma and Texas, but at present we do not have any at all definite data to make it clear how wide this zone is, and to what extent the representatives of the Chernozem soils occur in it."

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> "Unfortunately we do not have available chemical analyses of the different levels from typical soils of the prairies mentioned. The data of such analyses would make it possible for us to elucidate more fully the peculiarities of these soils and their real nature."[1]

Even for the Chernozem soils of Europe he finds, on assembling the available data, that only very few such analyses have been published, and even these are far from complete. Nabokich (22, p. 203) points out that there is still lacking a knowledge of the exact character of the vertical profile of most of the soil types of Europe, the chemical study of the successive soil levels begun more than thirty years ago by Dokutschajew, Schmidt, Berendt, Müller and others having been neglected by the soils investigators who followed them.

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[1] Author's translation from Kossowitsch, loc. cit.

As no other soils from the regions of summer rains have contributed so much to the study of the relation of soil character to climate as have the Chernozem soils of Russia, both the analytical data and the agricultural history of these are of especial interest in connection with the soils of the transition region. Because of their three most marked characteristics—great fertility, richness in organic matter and wide distribution—they early attracted the especial attention of Russian investigators, and the explanation of their origin has been a matter of controversy for over a hundred years. They occupy the greater part of the southeastern half of European Russia. Toward the north and northwest they pass gradually into the gray, forest-covered soils, there being no sharp line of separation, while on the southeast they assume a chocolate—or chestnut-color and merge into the light-colored soils of the desert areas. Thus with a steady increase in the humidity of the climate the light-colored soils of the southeast pass into those darker in color and these in turn into the typical black soils (Chernozem). With still increasing humidity the latter show a gradual change into the light gray forest soils. The productivity attains a maximum along with the color, the light desert soils being unproductive from lack of rainfall and the light-colored forest soils because of the lack of the essential elements of nutrition.

The climate of the Chernozem zone in Russia resembles that of western Nebraska in that it is cold in winter with a small snow-fall, has hot summers with a dry atmosphere, is subject to sudden changes of temperature, and is characterized by insufficient precipitation. This want of moisture is due less to the amount, 16 to 20 inches, than to its distribution. It falls chiefly during the warm, growing season, and is quickly transpired by the plants or evaporated. Much falls in heavy showers, causing a great loss in the form of run-off. The fineness of texture of the soils increases both the runoff and the evaporation. The natural vegetation is similar to that of our prairies, but Russian investigators report that it is very difficult to now find any really virgin fields.

The Chernozem soils occur chiefly on the loess and there is still found outside of Russia the erroneous view that they are *confined* to this geological formation. Extensive areas occur on the glacial plains, lacustral clays, limestone and crystalline rocks, sufficient evidence that this soil's formation depends upon the climate rather than upon the character of the parent rock. One property possessed in common by all geological formations on which this black soil is typically developed is their ability to produce a fine-textured product on weathering. The topography on which the Chernozem occurs is similar to that of our prairies—almost level to gently rolling.

It is now generally accepted that the grassland vegetation has caused the dark color of the Chernozem soils. The large quantities of roots left by the plants were not provided with conditions favorable to rapid decay, the soils being throughout most of the year either too dry or too cold. The plants, consisting largely of biennials or perennials rooted deeply, and the roots were of short life compared with those of forest vegetation. Thus large quantities of the dead roots were annually added to the soil. Considerable amounts of the aerial parts of the plants were dragged down by insects or fell into crevices during dry weather. It is not improbable that soluble organic compounds from the aerial parts were carried down into the soil by the rains, In passing from the most arid to the most humid portions of the plains the conditions favored an increased rate of growth but also an increased rate of decay. Up to a certain point the former increased the more rapidly and at that point there is found the maximum accumulation of organic matter.

Kossowitsch (20, p. 333) states that the Chernozem soils, both in physical and chemical respects, possess the very best properties which good arable soils must have, that in so far as the supply of plant nutrients is concerned they are to be classed with the most fertile, and that under cultivation they retain their fertility a very long time, which may amount to some hundreds of years. The actual conditions of climate that have produced these soils cause the years of rich harvests to alternate with those of light yields, during which the draught upon the soil is very light. Signs of exhaustion appear first in those derived from the poorer parent rocks and formed under a more humid climate. In general, the Chernozem soils begin to show first the lack of phosphoric acid and later that of nitrogen.

METHODS OF SAMPLING.

In an investigation such as this the method of taking the samples to be used for analysis is extremely important. We had planned to collect samples from each of the eight precipitation-belts shown in Fig. 2. None was secured from the 32 + or the 22 to 24 inch belt. On account of the recent series of dry years, McCook, which at the time of beginnig the work was regarded as in the 20 to 22 inch belt, now has to be placed along with Wauneta, which was selected as representative of the 18 to 20 inch belt.

TABLE I.

LONGITUDE, ELEVATION AND NORMAL PRECIPITATION AT TOWNS NEAR WHICH THE SOIL SAMPLES WERE COLLECTED.

Stations of the U.S. Wthr. Bur.	Approximate longitude	Elevation feet	Normal annual precipitation, inches	Length of record, years
Wauneta	101° 30′	2934	18.55	25
McCook	100° 40′	2506	18.83	[1]30
Holdrege	99° 20′	2324	24.24	20
Hastings	98° 20′	1932	26.87	22
Lincoln	96° 40′	1189	27.51	31
Weeping Water.	96° 10′	1080	30.19	37

[1] See footnote 2 to Table IV.

The soil samples were collected from only virgin prairie fields near one or other of the six stations of the United States Weather Bureau mentioned in Table I, for each of which a precipitation record of twenty years or more is available. The location of these is shown in Fig. 2.

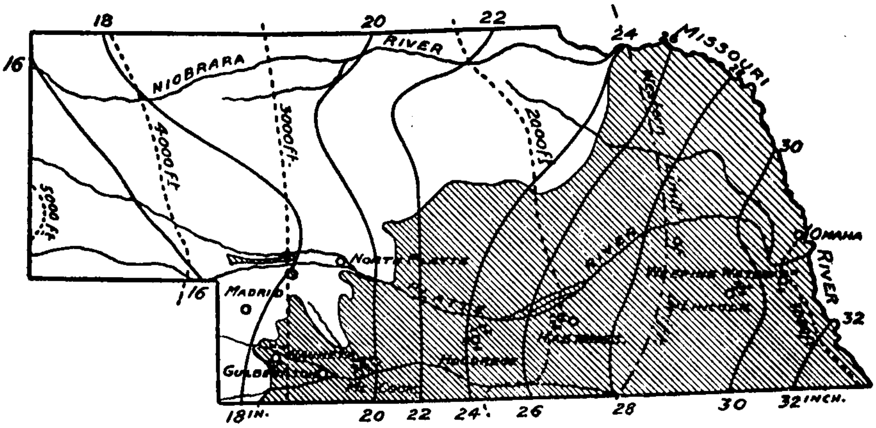

Fig. 2.—Map of Nebraska showing distribution of the loess, precipitation belts, the altitude and the location of fields sampled.

The original intention was to select in each locality five level, virgin fields located to one another as are the four corners and the center of a square whose sides are two miles in length. However, on account of the great scarcity of virgin fields which were at all level, the original plan could not be adhered to closely. Along the different river courses and in the southeastern counties, where the loess overlies the Kansan till, it has been extensively eroded, in the latter in many places remaining as only small isolated plains. Also in many places on the divides in the western portion it has been eroded, and in such cases, while not usually exposing the underlying geological formation, the surface coating with its high content of organic matter, characteristic of the level or rolling prairies, has been largely removed. Thus, while numerous virgin fields were found, only a few of these were representative of the tillable areas of loess soil. The very characteristics which we desired our typical fields to possess had appealed to the farmers and caused them early to bring such land under the plow. All fields in valleys were avoided, as were also those in which the loess was found to have a depth of less than six feet. We were, however, able to select in each of the six localities mentioned in Table I five fields which, since the advent of settlers,[1] have been used as pastures or as meadows, or partly for both purposes. None of these fields was more than ten miles from the Weather Bureau station whose name is given the area for the purpose of the present discussion. The legal description of each is reported in Table II. All, at least in the parts sampled, were almost level or only slightly rolling. Those of the two eastern areas, Weeping Water and Lincoln, had been used chiefly as meadows, while those of the areas to the west had been used mainly, or altogether, as pastures. The location of the selected fields with respect to the farmsteads, together with the system of farming followed, renders it improbable that there had been any additions of potash or phosphoric acid due to the application of fertilizers of any kind or to feed from elsewhere having been given the pasturing animals while on these fields. The amount of organic matter in the surface soil may be somewhat less in the fields used as meadows than would have been the case if they had been pastured, but it is probably fully as great as though they had been exposed to periodic prairie fires, such as prevailed before the settlement of the state. So, on the whole it seems extremely probable that the soil of the fields, when the samples were taken in 1909 and 1910, was similar in composition to what it was when *truly* virgin—before the advent of settlers. A typical field in each of the areas is shown in Plates I, II and III.

From each field two sets of samples were taken—the one consisting of the *foot-samples* and the other of the *inch-samples*. For the former ten borings, at intervals of 30 feet along a line across the most level portion of the field, were made to a depth of 6 feet, and composite samples prepared of each foot section, thus giving six samples, later referred to as "field-samples," which are not to be confused with the "area-samples," prepared by mixing equal weights of the corresponding five "field-samples." Two soil augers, one of 2.25 and the other of 1.5 inch diameter, were employed. The former was used for taking the samples of the surface foot, as well as for enlarging and cleaning out the hole preparatory to sampling each of the lower foot sections with the smaller auger. Great care was exercised to prevent any of the soil from nearer the surface becoming mixed with the samples from the lower levels. Thus, in addition to using augers of different sizes, carefully enlarging and cleaning the hole with the larger one before taking a section with the smaller, the auger, on being withdrawn with the attached soil, was closely examined for any material which might have come from nearer the surface, and if this was found it was removed with a knife. The aerial portions of living plants were not included with the sample, but roots and plant debris were treated as integral parts of the soil.

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[1] Mr. A. E. Sheldon has furnished the following approximate dates at which practically all of the Government land had been taken in the different localities: Weeping Water, 1865; Lincoln, 1870; Hastings, 1885; Holdrege, 1892; McCook, 1900; and Wauneta, 1904. He states also that settlements had been made about 1854 at Weeping Water, 1858 at Lincoln, and between 1869 and 1876 in the more westerly localities.

TABLE II.

LOCATION OF THE FIELDS FROM WHICH THE SOIL SAMPLES WERE TAKEN.

Field No.	Part of Section	Section	Township	Range	From 6th Principal Meridian
WAUNETA.					
I	W½ of NW¼	4	4	36	West
II	SE¼ of NE¼	23	6	36	West
III	SE¼	10	5	36	West
IV	E½ of NE¼	22	6	37	West
V	NE¼	34	5	36	West
McCOOK.					
I	SW¼ of SW¼	10	3	29	West
II	NE¼ of NE¼	10	3	29	West
III	N½ of NE¼	8	3	29	West
IV	W½ of SW¼	4	3	29	West
V	N½ of SW¼	8	3	29	West
HOLDREGE.					
I	N½ of NW¼	33	6	18	West
II	SE¼ of NW¼	7	5	18	West
III	E½ of NE¼	9	5	18	West
IV	N½ of NE¼	33	6	18	West
V	SE¼ of NW¼	34	6	18	West
HASTINGS.					
I	N½ of NE¼	17	7	10	West
II	SE¼ of NE¼	12	7	11	West
III	SE¼ of SE¼	16	7	10	West
IV	SE¼ of SE¼	4	7	10	West
V	SE¼ of SW¼	6	7	10	West
LINCOLN.					
I	Near center of SE¼	20	10	7	East
II	S½ of NE¼	29	10	7	East
III	E½ of SW¼	27	10	7	East
IV	E½ of E½	2	10	7	East
V	W½ of NW¼ of SW¼	23	10	7	East
WEEPING WATER.					
I	SE¼ of NW¼	27	11	11	East
II	SW¼ of NE¼	26	11	11	East
III	NE¼ of SW¼	14	10	11	East
IV	NW¼ of SW¼	33	11	12	East
V	N½ of SE¼	34	11	12	East

It seems highly probable that the six area-samples, each a composite from 50 individual borings, from any one area represent material originally alike, any marked differences between them being due to alterations that the material experienced since its deposition. The inch sections were taken from the first foot only, being composites of 20 (and in the fields of the Lincoln area of 50) individual samples. They were secured by means of a brass tube 1⅜ inches in diameter provided with a wide collar 6 inches from the end. The tube was forced into the ground until the collar rested firmly on the surface. The core was forced out and then, after first removing the soil to a depth of six inches by means of a spade, the second 6-inch layer was sampled in the same manner. Each of the two cores thus obtained was subdivided into six equal lengths, the first inch section having the living vegetation trimmed off level with the surface of the soil. The area inch-samples, accordingly, are composites of 100, or 250, individual samples.

In all 648 samples were subjected to more or less complete analysis in this investigation, each of the six areas being represented by 108, consisting of 36 foot-samples and 72 inch-samples.

THE CLIMATE.[1]

The altitude of the loess-covered portion of Nebraska rises gradually from east to west; all the Weeping Water fields sampled touch the 1200 foot contour line while all those at Wauneta are from 3100 to 3400 feet above the sea level.

The gradual change in altitude from east to west is not accompanied by a corresponding change in temperature, the uniformity of which, throughout the region studied, is shown by Table III, in which are given the data for four of the stations. There is no record for Wauneta, and only a very incomplete one for Weeping Water, but conditions at these two stations differ little from those at McCook and Lincoln, respectively. The mean annual temperature is 50.1° F. at Lincoln and 51.8° at McCook. February, the coldest month, shows a mean of 24.8° at the former and 27.7° at the latter, and July, the warmest month, of 76.4° and 77.4°, respectively. In most years maximum temperatures of about 100° are recorded a few times during the warm season, July, August and the early part of September, and minimum temperatures of 15° to 20° below zero during the winter months. Occasionally temperatures as high as 110° and as low as 30° below zero occur. The season without killing frosts usually extends from the first of May to the first week in October, but these have been experienced as late as the last week in May and as early as the second week in September.

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[1] For the data on climate we have made use of the various publications of the United States Weather Bureau dealing with Nebraska, especially the Summaries of the Climatological Data for the United States for Sections 35, 36 and 37, the Annual Summaries for the Nebraska Section, and the Annual Reports of the Chief of United States Weather Bureau. In addition, unpublished data have been furnished us by Mr. G. A. Loveland, Director of the Nebraska Section of the Bureau.

TABLE III.

TEMPERATURE DATA, IN DEGREES FAHRENHEIT, FOR THE DIFFERENT STATIONS.

MEAN TEMPERATURES.

Station	Length of Record, Yrs.[1]	January	February	March	April	May	June	July	August	September	October	November	December	Annual
McCook	14	27.8	27.7	39.0	51.3	62.6	72.5	77.4	76.5	66.6	53.4	38.7	28.0	51.8
Holdrege	20	26.0	26.7	37.2	50.9	60.9	71.9	76.6	75.2	67.2	52.8	38.5	28.5	51.0
Hastings	22	24.4	24.7	36.9	50.1	60.6	71.5	75.6	74.4	65.3	52.8	38.8	26.8	50.0
Lincoln	31	21.2	24.8	36.0	50.7	62.9	71.6	76.4	74.3	65.2	53.3	38.0	26.9	50.1
HIGHEST RECORDED TEMPERATURES.														
McCook	14	78	74	91	98	101	106	110	107	102	94	85	71	110
Holdrege	20	70	78	92	101	102	106	108	108	115	92	88	65	115
Hastings	22	70	71	90	93	96	103	108	104	101	91	78	66	108
Lincoln	31	66	79	91	97	98	103	110	107	103	92	80	71	110
LOWEST RECORDED TEMPERATURES.														
McCook	14	*30	*38	*5	18	14	44	44	40	22	12	*8	*21	*38
Holdrege	20	*26	*43	*9	10	19	38	42	42	29	7	*8	*12	*43
Hastings	22	*30	*30	*5	18	22	41	48	43	28	9	*5	*13	*30
Lincoln	31	*29	*26	*11	17	25	43	49	43	27	15	*15	*18	*29

[1] Including 1914.

* Below zero.

The precipitation (Table IV) decreases from east to west, the mean annual amount being a little more than 30 inches at Weeping Water and a little less than 19 at Wauneta, or an average decrease of about one inch for each 25 miles. Most of it falls during the growing season, and only less than one-tenth of it during the three winter months. June is the month of maximum precipitation and January of minimum. About half of the rainfall of May, June and July is from rains of one inch or more in 24 hours. In most years some part of the region has a storm with a rainfall exceeding 2 inches in 24 hours and occasionally this rises to 5 or even 8 inches. The fall of such a large part of the total precipitation in the form of these storms of brief duration accounts largely for the observed deficiencies of moisture for crops in seasons when the recorded rainfall would indicate an abundant supply, much of the water running off the surface before there is time for it to be absorbed by the soil. The number of days with a precipitation of 0.01 inch or more decreases from east to west more rapidly than does the total precipitation, averaging over 80 at Weeping Water and Lincoln and less than 50 at Holdrege and McCook. For those days on which the precipitation amounts to 0.01 inch of more it averages 0.34 inch at Weeping Water, 0.32 at Lincoln, 0.40 at Hastings, 0.52 at Holdrege, 0.43 at McCook, and 0.36 at Wauneta.

TABLE IV.

PRECIPITATION DATA, IN INCHES, FOR THE DIFFERENT STATIONS.

AVERAGE PRECIPITATION.

Station	Length of Record, Yrs.	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Wauneta[1]	25	0.26	0.69	1.03	2.04	2.54	3.34	2.47	2.74	1.35	1.13	0.39	0.57	18.55
McCook[2]	14	0.21	0.62	0.73	1.89	2.82	3.29	3.09	2.55	1.72	1.03	0.56	0.57	19.08
Holdrege	20	0.41	0.90	1.02	2.77	4.17	3.71	3.19	3.08	2.07	1.59	0.63	0.70	24.24
Hastings	22	0.44	1.05	1.13	2.77	3.64	4.24	3.62	3.59	2.73	2.02	0.80	0.83	26.87
Lincoln	31	0.62	0.70	1.33	2.77	4.25	4.32	3.83	3.71	2.64	1.82	0.85	0.67	27.51
W. Water	37	0.89	1.04	1.40	2.49	4.19	4.86	3.71	3.88	3.14	2.34	1.24	1.01	30.19
HIGHEST PRECIPITATION RECORDED SINCE 1894.														
Wauneta	20	0.80	2.00	3.50	4.05	5.50	7.16	9.38	5.78	3.80	3.90	2.15	3.25	32.24
McCook	20	0.70	2.32	2.85	4.96	6.87	5.63	10.86	4.60	4.53	4.65	2.02	3.19	33.97
Holdrege	20	0.90	2.20	4.25	7.90	12.36	11.83	7.15	6.19	5.05	4.35	2.58	4.19	40.21
Hastings	20	1.25	2.50	3.02	9.26	10.92	7.91	10.62	9.86	6.87	5.82	3.32	4.93	39.01
Lincoln	20	1.15	2.13	3.67	5.11	10.72	11.24	11.35	14.21	7.60	3.62	7.14	4.03	41.22
W. Water	20	2.16	2.83	3.62	4.42	11.45	12.24	10.26	10.00	9.10	3.91	9.20	3.96	41.09
LOWEST PRECIPITATION RECORDED SINCE 1894.														
Wauneta	20	0	0	0	0.12	0.20	0.65	0.73	0.30	0	0	0	0	13.13
McCook	20	0	0	0	0.05	0	0.66	0.40	0.36	0.20	T	0	0	9.34
Holdrege	20	T	T	0	T	0.30	0.85	0.50	0.95	0.25	0	0	0	16.26
Hastings	20	T	T	0.16	0.36	0.64	0.38	0.55	0.79	0.60	T	0.04	T	18.81
Lincoln	20	0.07	0.07	0.10	0.02	0.96	0.56	1.05	0.31	0.39	0.05	0.03	0.02	16.38
W. Water	20	0.10	0.10	0.10	0.18	0.55	0.39	0.73	1.25	0.38	0.11	T	0.09	21.06
AVERAGE NUMBER OF DAYS WITH .01 INCH OR MORE OF PRECIPITATION.														
Wauneta	12	1	3	3	5	7	8	6	6	4	3	2	3	51
McCook	20	2	3	3	5	5	7	5	6	3	2	1	2	44
Holdrege	23	2	3	2	4	6	7	6	5	4	3	2	3	47
Hastings	20	3	4	4	7	9	10	7	7	5	4	2	3	65
Lincoln	27	4	5	7	8	12	10	9	9	7	6	4	5	86
W. Water	28	5	6	7	9	11	11	8	8	7	6	3	4	85

[1] Data previous to November 1, 1901, from Ough, 10 miles north of Wauneta.

[2] The mean for McCook for 30 years, using the record from 1882 to 1890 at Red Willow and that from 1892 to 1895 at Indianola, is 18.83 inches. The monthly means are all very similar to those here given.

The drouth frequency during the crop-growing season increases quite uniformly from east to west. Defining a *drouth period* as 30 consecutive days or more in which precipitation to the amount of 0.25 inch does not occur, the United States Weather Bureau has recently shown that the total number of drouth periods between March 1 and September 30 for the 20-year period, 1895 to 1914, inclusive, is 15 at Lincoln and 30 near the western edge of the loess.[1]

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[1] Chart in National Weather and Crop Bulletin, May 5, 1915.

TABLE V.

RELATION OF THE ANNUAL PRECIPITATION, YEAR BY YEAR, TO THE NORMAL (= 100).

Station	Wauneta[1]	McCook	Holdrege	Hastings	Lincoln	W.Water
Normal, in inches	18.55	18.83	24.24	26.87	27.51	30.19
1895............	90	[2] 98	88	90	60	70
1896............	71	107	124	127	138	128
1897............	113	109	119	125	93	77
1898............	113	97	75	93	102	89
1899............	66	73	[4] 114	70	82	101
1900............	81	75	[5] 104	103	123	114
1901............	104	105	92	85	80	83
1902............	...	135	[6] 155	145	150	135
1903............	...	118	[7] 146	137	126	106
1904............	134	112	[8] 101	85	101	81
1905............	174	178	166	137	129	118
1906............	130	108	127	87	124	79
1907............	109	101	94	83	99	103
1908............	134	[3] 95	113	119	130	122
1909............	99	..	90	90	126	136
1910............	76	49	77	84	114	79
1911............	101	64	90	89	89	84
1912............	108	77	73	95	81	89
1913............	86	..	83	89	95	108
1914............	93	96	67	86	145	89

[1] The record previous to November 1, 1901, kept at Ough, 10 miles south of Wauneta.
[2] For Bartley, 17 miles to the east.
[3] Datum for February from Culbertson, 12 miles to the west.
[4] Data for June and August from Kearney, 24 miles northeast.
[5] Datum for March from Kearney, 24 miles northeast.
[6] Datum for September from Kearney, 24 miles northeast.
[7] Data for March and November from Kearney, 24 miles northeast.
[8] Datum for June from Kearney, 24 miles northeast.

The relation of the annual precipitation to the normal at the different stations since 1894 is shown in Table V. The data for the years previous to 1895 are, in the case of so many of the stations, either missing or so incomplete that they do not permit of comparisons. The greatest departures shown are +78 per cent at McCook in 1905, and -40 per cent at Lincoln in 1895. Neither the greatest departures from the normal, nor the relative frequency of the years with an excess or a deficiency of precipitation (Table VI) shows any distinct relation to the longitude.

The average annual snowfall is a little less than 24 inches, it being about one inch heavier in the west than in the east. "As a rule snow covers the ground but a few days at a time after each snow storm, and the ground is covered with snow less than half of the time even during the months of the heaviest snowfall."[1] Much of the snow is swept by

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[1] Loveland, G. A., Summary of Climatological Data for the United States, Sec. 37, Southern Nebraska, p. 1.

high winds into the depressions, and so contributes but little to the supply of soil moisture of the land upon which it falls. The snowfall exerts little effect upon the leaching of the soil, although agriculturally, as in the wintering of fall-sown grains, it may be very important.

TABLE VI.

THE RELATIVE FREQUENCY OF THE YEARS WITH PRECIPITATION BELOW OR ABOVE NORMAL.

Per Cent of Normal	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	W.Water %
Below 71	6	12	5	5	5	5
71 to 90	28	16	35	50	20	45
91 to 110	33	48	20	15	25	20
111 to 130	16	12	25	15	35	20
131 to 150	11	6	5	15	15	10
Above 150	6	6	10	0	0	0

The prevailing winds are from the south or southeast during the growing season and from the northwest or north during the rest of the year. An accurate record of the velocity has been kept at only one of the six stations mentioned in Table I, viz. Lincoln. However, records are available for two other stations, Omaha and North Platte, both in the loess region, the former being about 30 miles northeast of Weeping Water and with a similar normal annual precipitation (30.66 inches) and the latter 65 miles north of McCook with a normal precipitation of 18.86 inches. At Omaha the anemometer is placed at an elevation of 121 feet, at Lincoln of 84 and at North Platte of 51. At the last the station is located in the valley of the Platte River and for this reason the velocity may be considerably lower than on the surrounding plains. An experimental substation of the University of Nebraska is situated about four miles south of North Platte and here, since 1907, a very complete meteorological record has been kept, the instruments being placed on the exposed plain at an elevation of 2985 feet, about 108 feet above the United States Weather Bureau station in the valley. Here the anemometer is two feet above the surface of the ground. The record for six months, April to September, inclusive, for the years 1908 to 1914, which has been furnished us by Mr. W. P. Snyder, has been compared with that from the United States Weather Bureau station for the same months. There are slight differences from month to month, but the average difference is very small, it being about 0.2 miles higher at the experimental substation. Accordingly we may safely assume that the data for North Platte reported in Table VII correctly represent the wind velocity near the surface of the ground on the western plains. While the average velocity recorded is 11 miles per hour at Lincoln, 10 at North Platte and 9 at Omaha, it seems probable that near the surface it would at present be much lower at Lincoln and Omaha, especially on account of the large number of planted trees now growing. However, there appears to be no evidence that the wind velocity near the ground was not comparatively uniform throughout the region under discussion previous to the advent of settlers.

TABLE VII.

AVERAGE HOURLY WIND MOVEMENT (IN MILES PER HOUR).

Station	Length of Record, Yrs.[1]	January	February	March	April	May	June	July	August	September	October	November	December	Annual
North Platte	40	9	9	11	12	12	10	9	9	9	9	9	8	10
Lincoln	20	11	11	13	14	12	10	9	9	10	11	11	10	11
Omaha	43	9	9	10	11	9	8	7	7	8	8	9	9	9

[1] Including 1914.

Data on the relative humidity are available for North Platte, Lincoln and Omaha (Table VIII). The normal is very similar at all three stations, being 71, 70 and 69 per cent, respectively, while the mean at 8 a. m. is 83, 80 and 78 per cent, and that at 8 p. m., 58, 60 and 61 per cent. Occasionally the humidity during the afternoon in summer falls below 10 per cent in the west and 20 per cent in the east. Thus the data show a very slightly greater humidity in the western part of the region than in the eastern. It is of interest in this connection that according to popular opinion in Nebraska the air is very much drier in the western part.

TABLE VIII.

THE MEAN RELATIVE HUMIDITY.

Station	Length of Record, Yrs.[1]	Hour of Observation	January	February	March	April	May	June	July	August	September	October	November	December	Annual
North Platte	27	8 A.M.	83	84	83	80	83	84	85	88	85	83	79	81	83
		8 P.M	69	67	60	51	54	56	54	55	52	54	57	65	58
		Avg.	76	76	72	66	69	70	70	72	68	69	68	73	71
Lincoln	18	8 A.M	80	83	80	75	79	81	80	84	81	79	77	80	80
		8 P.M	67	68	61	52	57	57	55	58	56	58	62	68	60
		Avg.	73	75	70	63	68	69	67	71	68	68	69	74	70
Omaha	27	8 A.M.	81	81	78	73	75	78	77	79	80	76	77	81	78
		8 P.M.	71	69	63	53	55	56	55	57	59	55	62	70	61
		Avg.	76	75	71	63	65	67	66	68	69	65	70	75	69

[1] Including 1914.

The data on the relative insolation are rather too limited to permit of definite deductions. The number of cloudy days is much greater in the east than in the west (Table IX), while the available data show much less difference in the total number of hours of sunshine (Table X), a rather surprising condition. At North Platte it averages 9 per cent more than at Omaha and 3 per cent more than at Lincoln. In this respect Lincoln resembles North Platte more than it does Omaha.

TABLE IX.

AVERAGE NUMBER OF CLEAR, PARTLY CLOUDY AND CLOUDY DAYS FOR THE SEVEN YEARS, 1908 TO 1914.

Station	Clear Days	Partly Cloudy Days	Cloudy Days
North Platte	175	115	75
Lincoln	140	111	114
Omaha	132	115	118

TABLE X.

PERCENTAGE OF POSSIBLE NUMBER OF HOURS OF SUNSHINE FOR THE SEVEN YEARS, 1908 TO 1914.

	North Platte %	Lincoln %	Omaha %
January	64	55	51
February	65	58	54
March	69	68	58
April	67	66	59
May	64	66	60
June	74	73	66
July	78	76	70
August	73	74	66
September	68	63	59
October	66	61	61
November	64	60	53
December	58	56	52
Year	68	65	59

The data on the rate of evaporation from a water surface are scanty. Russell (25, p. 10; 26, p. 558) by applying a formula to observed meteorological conditions calculated the evaporation for the entire year to be 38 or 40 inches in the extreme eastern part of Nebraska, 50 inches in the western and possibly 60 inches in the extreme southwestern corner. These are to be regarded as only rough approximations of the correct values. For Lincoln there is a record for the months of April to October from 1899 to 1909, the average for the six months, April to September inclusive, being 34.8 inches (21). As the average mean temperature, relative humidity and wind velocity for these eleven years are very similar to the normals based upon the entire record since observations were begun, it is safe to assume that this represents the normal evaporation. At the North Platte substation a record has been kept beginning with 1907. The average for the six months is 45.06 inches. As during this eight-year period both the average mean relative humidity and the average wind velocity have been lower than normal it is not possible to decide just how closely the average for these years represents the actual normal at North Platte, but probably it does not depart widely. The data are reported in Table XI. The two totals 45.06 and 35.93 inches, it should be observed, are not for the entire year, the measurements being made for only the months in which there is little freezing. The evaporation tanks were placed so that the water surface was kept at the level of the ground. The tank at Lincoln was 3 feet square and 10 inches deep, (21, p. 193) and that at North Platte 6 or 8 feet in diameter and 2 feet deep (9, p. 382). The one at Lincoln may have been somewhat protected, by neighboring buildings and trees, from the full sweep of the south and southwest winds, but on the whole the conditions were such as to make the records satisfactorily comparable.

TABLE XI.

EVAPORATION FROM A FREE WATER SURFACE AT NORTH PLATTE AND LINCOLN.

	April Inches	May Inches	June Inches	July Inches	Aug. Inches	Sept. Inches	Tl. 6 mos. Inches
No. Platte, 1907 to 1914	5.92	6.78	8.54	9.00	8.41	6.41	45.06
Lincoln, 1895 to 1910..	4.71	5.85	6.57	7.57	6.39	4.84	35.93

Bigelow (8, p. 5) reports the annual evaporation at Dutch Flats at the western edge of the state, to be 65.67 inches for the years 1909-1910, using a tank 4 feet in diameter. As observations were not made for the winter months the rates for these were found by interpolation.

The relative evaporation from a free-water surface depends upon the intensity of the solar radiation and the cloudiness, as well as upon the temperature, the relative humidity of the air and the wind velocity. Throughout the region under consideration the last three factors are found to be very uniform, while the first also is to be regarded as uniform, but the cloudiness decreases as we proceed from east to west. To this difference in the amount of sunshine we must attribute the observed differences in the rate of evaporation. Although there are no records of the evaporation in the central portion, represented by Hastings and Holdrege, it seems safe to assume that there it is intermediate between that at Lincoln and that at North Platte, while that at both McCook and Wauneta may be considered very similar to that at North Platte.

To summarize the climatic relations we may state that as we proceed from east to west there is experienced a gradual decrease in the total precipitation and in the cloudiness, with an increase in the rate of evaporation from a water surface and in the frequency of drouths, while the distribution of rainfall and snowfall, the temperature conditions, the wind velocity and the relative humidity remain quite uniform.

HYGROSCOPICITY.

As the variations in the hygroscopicity of soils are due to variations in texture a determination of the former serves to indicate the uniformity in texture of a series of samples. This single-valued expression of the relative heaviness of soils was suggested by Hilgard in 1860 (15, p. xi). The simple method of determining this value which he later designates the "hygroscopic coefficient" (16, p. 16; 17, p. 17)—the percentage of water absorbed by a dry soil from a saturated atmosphere—probably serves quite as well as the more complicated and time-consuming method later developed by Rodewald and Mitscherlich (24). Briggs and McLane (10; 11, p. 140) have introduced a somewhat similar method of expressing the relative texture of soils as a single factor—the "moisture equivalent," defined as the "maximum percentage of moisture a soil can retain in opposition to a centrifugal force equal to 1000 times the force of gravity." Briggs and Shantz (12, p. 64) have concluded that this may serve as an indirect method for the determination of the hygroscopic coefficient, the latter being 0.37 times the moisture equivalent. This method may have some advantages in convenience of execution, the absence of any need of a constant-temperature room, the lesser skill required on the part of the operator and a somewhat closer concordance of duplicate determinations, but these may be in many cases more or less completely offset by the cost of the apparatus required and the difficulties in installation. Further the moisture equivalent in itself expresses only the relative texture while the hygroscopic co-efficient does this quite as well, and at the same time indicates the lower limit of moisture available for the support of life of other than strictly xerophytic plants (1).

The data reported in Tables XII and XIII are the averages of concordant duplicate determinations made by exposing the air-dried soil in a layer *ca* 1 mm. in thickness to a saturated atmosphere for 24 hours, the temperature of the air not varying more than 1°C during the period.

In Table XII there are reported the hygroscopic coefficients of the foot sections from each of the thirty fields, and in Table XIII the averages for the foot levels of the different areas, each value in the latter table thus representing a composite sample from 50 borings and also the average of 10 determinations. In Table XIV are reported the averages of the coefficients for the six-foot sections from the different fields, each value here representing a composite of 60 individual samples and the average of 12 determinations.

TABLE XII.
HYGROSCOPIC COEFFICIENTS OF THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
WAUNETA.						
1	9.9	9.0	8.7	7.9	9.8	9.1
2	10.3	9.3	9.2	9.0	10.2	9.6
3	10.8	9.6	8.9	9.4	9.7	9.7
4	10.7	10.3	9.5	9.4	9.7	9.9
5	9.7	9.0	9.9	7.8	8.8	9.0
6	8.8	7.6	9.7	6.9	8.4	8.3
Average	10.0	9.1	9.3	8.4	9.4	9.2
McCOOK.						
1	10.6	9.6	10.0	10.3	9.6	10.0
2	11.6	11.0	10.1	11.2	10.8	10.9
3	10.9	11.8	9.8	10.7	10.1	10.7
4	9.5	10.5	8.9	10.2	9.3	9.7
5	9.0	10.3	8.5	9.1	8.7	9.1
6	9.6	10.4	8.2	8.9	8.5	9.1
Average	10.3	10.6	9.2	10.1	9.5	9.9
HOLDREGE.						
1	10.6	10.0	9.5	10.4	9.9	10.1
2	11.3	11.0	10.3	11.9	11.5	11.2
3	10.8	11.0	11.7	11.4	11.8	11.3
4	9.6	10.1	10.2	10.0	10.9	10.2
5	8.8	9.1	9.7	9.3	10.8	9.5
6	8.5	9.0	9.5	8.8	11.0	9.4
Average	10.0	10.0	10.1	10.3	11.0	10.3
HASTINGS.						
1	9.4	9.1	10.3	9.1	10.0	9.6
2	11.4	11.2	11.4	12.0	11.9	11.6
3	12.8	11.7	12.0	13.3	12.4	12.4
4	11.1	11.2	11.0	11.6	10.5	11.1
5	10.7	10.4	10.5	11.3	10.6	10.7
6	10.8	10.1	10.4	11.1	11.0	10.7
Average	10.9	10.6	10.9	11.4	11.1	11.0
LINCOLN.						
1	10.9	12.2	11.7	13.4	11.7	12.0
2	14.4	15.1	13.8	15.2	13.5	14.4
3	14.3	14.0	12.5	14.1	13.1	13.6
4	13.6	13.2	12.2	13.9	12.7	13.1
5	13.2	13.1	12.2	12.5	12.6	12.7
6	12.8	13.0	12.3	12.4	12.7	12.6
Average	13.2	13.4	12.5	13.6	12.7	13.1
WEEPING WATER.						
1	12.0	12.4	12.6	12.0	11.6	12.1
2	13.3	13.7	14.4	13.4	13.5	13.7
3	14.4	13.8	14.1	13.6	13.9	14.0
4	12.8	13.1	13.8	12.6	12.8	13.0
5	12.6	12.5	13.4	12.5	12.2	12.6
6	12.3	12.4	13.2	12.6	12.2	12.5
Average	12.9	13.0	13.6	12.8	12.7	13.0

TABLE XIII.

HYGROSCOPIC COEFFICIENTS OF THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	9.1	10.0	10.1	9.6	12.0	12.1	10.5
2	9.6	10.9	11.2	11.6	14.4	13.7	11.9
3	9.7	10.7	11.3	12.4	13.6	14.0	11.9
4	9.9	9.7	10.2	11.1	13.1	13.0	11.1
5	9.0	9.1	9.5	10.7	12.7	12.6	10.6
6	8.3	9.1	9.4	10.7	12.6	12.5	10.5
Average	9.2	9.9	10.3	11.0	13.1	13.0	11.1

The hygroscopicity is, on the whole, strikingly uniform, both from field to field in any one area and from the surface downward in the same field. It is lowest in the two western areas, in the fields of which it is similar, and highest in the two eastern in which also it is similar. Considering the six depths from the individual fields it is seen to show a maximum in either the second or third foot in 28 of the fields, while in the other two—II and III at Wauneta—it is higher in the fourth foot, but by less than 1 per cent. Comparing the values for these two feet it will be seen that there is no regularity, the maximum being shown in the second foot of all the Lincoln field, and in the third foot of all those at Hastings, while in each of the four other areas some fields show the maximum in the second and others in the third foot. The average for all thirty fields is 11.9 for both the second and the third foot. The values for the fifth foot are in general practically the same as for the sixth. The minimum value in the three eastern areas is found in the first foot, and in the three western in the sixth.

TABLE XIV.

AVERAGE HYGROSCOPIC COEFFICIENTS FOR THE DIFFERENT FIELDS.

Field No.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.
I	10.0	10.3	10.0	10.9	13.2	12.9
II	9.1	10.6	10.0	10.6	13.4	13.0
III	9.3	9.2	10.1	10.9	12.5	13.6
IV	8.4	10.1	10.3	11.4	13.6	12.8
V	9.4	9.5	11.0	11.1	12.7	12.7
Average	9.2	9.9	10.3	11.0	13.1	13.0

If we compare the averages for the five fields (Table XIV) it will be seen that those for Weeping Water are similar to those for Lincoln, the maximum value for the ten fields being 13.6 and the minimum 12.5; the Hastings fields all show lower values, from 10.6 to 11.4, while those for Holdrege, from 10.0 to 11.0, are similar; the fields at McCook, 9.2 to 10.6, and at Wauneta, 8.4 to 10.0, have averages which are slightly lower, but three of the McCook and one of the Wauneta fields show values practically the same as four of those at Holdrege. The uniformity may be well illustrated by pointing out that, in estimating the free moisture in the first six feet of soil in any one of the ten fields in the two eastern areas, it would give entirely satisfactory results to employ the average value, 13.0, instead of using the values actually found for the different fields. For those at Hastings we could use 11.0, and for those at Holdrege and McCook, 10.0. The maximum difference between two fields in the same area is shown at Wauneta where Field IV, which is at the actual border of the loess (Plate III, Fig. 1), the samples being collected a quarter of a mile from the edge, shows a lower value than any other field.

The uniformity in texture of the loess is illustrated by the data in Table XV from a single ranch near Madrid, the samples being taken from a type of soil which has later been mapped by the Bureaus of Soils of the United States Department of Agriculture as Sidney Silt Loam, "the weathered product of one of the late Tertiary deposits."[1]

TABLE XV.
HYGROSCOPIC COEFFICIENTS OF TEN SETS OF SOIL SAMPLES FROM A SINGLE RANCH NEAR MADRID, NEBRASKA.

Depth Ft.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
1	7.8	8.5	8.0	7.5	2.0	5.9	8.5	7.0	5.3	1.9
2	10.4	9.8	9.8	10.5	2.8	6.3	10.2	7.8	5.1	1.8
3	10.2	9.8	11.3	9.2	2.5	6.4	12.4	9.3	3.3	1.7
4	7.0	8.3	7.7	6.9	4.5	7.1	13.1	13.0	3.0	1.5
5	7.0	6.9	6.4	6.6	5.9	7.7	12.2	14.2	3.0	1.8
6	7.8	7.4	6.3	6.9	6.7	9.3	9.0	12.8	1.9	1.9

The proportion of organic matter in the surface foot is highest in the fields of the eastern areas, those in which, as above mentioned, the hygroscopic coefficient shows a minimum in the surface foot. This would suggest that the organic matter exerts little, if any, influence in increasing the hygroscopicity. This view is confirmed by the data presented in Table XVI, giving the hygroscopic coefficients for the different inch sections from each of the areas. From Table XXIX below it will be seen that the organic matter decreases rapidly from the surface downward, the range exceeding 100 per cent for each of the areas. The hygroscopic coefficient, on the other hand varies but little and tends to show an increase, rather than a decrease, from the surface downward. Either the organic matter exerts no effect upon the hygroscopicity, or, as seems more probable, the soil of the first foot, as we proceed from the surface downward, increases in fineness of texture to such an extent that it more than counterbalances the influence of the decrease in organic matter.

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[1] Bur. Soils—1913—Reconnoissance Survey of Western Nebraska, U. S. Dept. Agr., Bur. Soils, Field Operations of 1911.

TABLE XVI.

HYGROSCOPIC COEFFICIENTS OF THE DIFFERENT INCH SECTIONS FROM THE DIFFERENT AREAS. EACH IS A COMPOSITE OF 100 OR MORE INDIVIDUAL SAMPLES.

Depth In.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	8.5	8.5	10.9	10.9	11.5	11.5	10.3
2	8.2	8.3	10.3	9.7	11.2	11.0	9.8
3	8.2	8.4	9.9	8.9	11.0	11.0	9.6
4	8.3	8.3	9.5	8.5	11.1	11.1	9.5
5	8.2	8.7	9.4	8.3	11.4	11.2	9.5
6	8.6	9.3	9.4	9.0	11.8	11.2	9.9
7	8.7	9.5	9.7	9.5	11.9	11.5	10.1
8	8.8	9.8	9.9	9.5	12.1	12.1	10.4
9	8.6	9.9	10.0	9.5	13.0	12.3	10.6
10	8.8	10.3	10.9	9.7	12.6	12.6	10.8
11	9.0	10.3	10.2	10.0	12.9	12.5	10.8
12	8.7	10.2	10.2	10.2	13.1	12.8	10.9
Average	8.6	9.3	10.0	9.5	12.0	11.7	10.2

If the hygroscopicity is but little influenced by an increase in the organic matter of the soil while the water-holding capacity is distinctly increased, the effect upon crop growth of this increase will be much greater than would be expected from the relative change in the total water content, as the increase will be confined to the available portion of the soil moisture.

TABLE XVII.

HYGROSCOPIC COEFFICIENTS OF THE DIFFERENT INCH SECTIONS FROM THE FIVE FIELDS NEAR LINCOLN.

Depth In.	Field I	Field II	Field III	Field IV	Field V	Average
1	11.2	10.5	10.9	12.2	11.5	11.3
2	9.3	10.6	11.8	12.5	11.1	11.1
3	8.9	10.7	11.3	12.2	11.1	10.8
4	8.9	11.1	11.7	13.0	11.1	11.2
5	9.2	11.3	11.4	12.6	11.5	11.2
6	9.3	11.4	11.6	12.6	11.8	11.3
7	9.3	11.6	12.1	13.3	11.9	11.6
8	9.5	11.8	12.1	13.6	11.9	11.8
9	9.4	12.5	12.6	14.1	11.8	12.1
10	10.0	12.8	13.2	14.5	12.0	12.5
11	10.0	13.9	13.2	15.1	12.4	12.9
12	10.1	14.7	13.9	14.6	13.6	13.4
Average	9.6	11.9	12.2	13.4	11.8	11.8

Only in the case of the Lincoln area were the field inch-sections subjected to the determination of the hygroscopic coefficient. (Table XVII). It will be seen that there is quite as much difference between the sections from Fields I and IV as between the two most dissimliar sets of area-samples. In these also there is to be found no connection between the relative amounts of organic matter and the hygroscopicity (Table XXVII). The organic carbon in the inch-sections from the individual fields was not determined but the nitrogen was, and as will be shown below the latter bears an almost constant relation to the former. The inch-samples from Field I show the highest content of nitrogen (Table XXI) but the lowest hygroscopic coefficients, while Field IV in which the latter values are highest is the one next to the lowest in nitrogen—additional evidence of the slight influence of the organic matter upon the hygroscopicity. However, the high hygroscopic coefficients for peat soils, containing from 80 to 95 per cent organic matter, which we have found to be from 50 to 60, indicate that the organic matter should be expected to exert at least a slight effect in the case of the prairie soils.

NITROGEN.

Nitrogen was determined in all the field foot-samples (Table XVIII) and field inch-samples (Table XXI), the average of these furnishing the data for the area samples (Tables XIX and XXII). The average nitrogen content for the six feet of each field is given in Table XX.

In all the fields the nitrogen, as was to be expected, decreases from the surface downward. The few cases in which it is found slightly lower in the fourth or fifth foot than in the sixth, as in Wauneta III and McCook I, may safely be attributed to the experimental error of sampling or of analysis. It decreases from east to west. According to the amount in the surface foot, the fields fall into three groups: one with .125 to .146, another with .164 to .209, and the third with .228 to .245 per cent. All the Wauneta and McCook fields are in the first, those at Holdrege and Hastings in the second and those at Lincoln and Weeping Water in the third. This separation into three groups holds also when we consider the averages of the inch-sections from each field (Table XXI), a distinct set of samples.

On the basis of the nitrogen content of the second foot two groups are recognizable, the one including all the fields of the two eastern areas with .078 to .111 and the other those of the four western with .122 to .171 per cent. While the first foot of the Lincoln fields is similar in nitrogen to that of those at Weeping Water, the second foot is lower in the former than in the latter. In the fields of these two eastern areas the nitrogen in the second foot is similar to that in the first foot of the McCook and Wauneta areas. The differences in the third and lower foot are not sufficient to permit of any grouping of areas, although the nitrogen content is in general higher in the eastern than in the western sub-soils from the same depth.

The differences between areas are not so regular when the averages for the fields are compared (Table XX), Fields II and IV at Hastings, for instance, showing a lower content than II at McCook or III at Wauneta. The differences in the nitrogen content of the first foot in the different areas might be due, partly or wholly, to differences in texture, a coarser

TABLE XVIII.
NITROGEN IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

WAUNETA.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.135	.138	.144	.129	.132	.136
2	.080	.078	.092	.082	.079	.082
3	.059	.058	.072	.078	.060	.065
4	.043	.056	.042	.047	.043	.046
5	.033	.035	.049	.039	.036	.038
6	.028	.025	.049	.023	.027	.030
Average	.063	.065	.075	.066	.063	.066

McCOOK.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.143	.146	.138	.143	.125	.139
2	.079	.090	.080	.088	.085	.084
3	.048	.067	.052	.052	.049	.054
4	.036	.049	.037	.036	.034	.038
5	.031	.037	.034	.029	.031	.032
6	.034	.031	.030	.029	.027	.030
Average	.062	.070	.062	.063	.059	.063

HOLDREGE.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.172	.174	.164	.189	.209	.182
2	.089	.098	.111	.104	.103	.101
3	.055	.064	.074	.075	.055	.065
4	.038	.043	.053	.056	.037	.045
5	.031	.038	.040	.032	.027	.034
6	.034	.034	.039	.034	.028	.034
Average	.070	.075	.080	.082	.076	.077

HASTINGS.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.171	.174	.183	.169	.174	.174
2	.095	.095	.102	.093	.104	.098
3	.059	.053	.062	.054	.059	.057
4	.043	.039	.044	.032	.046	.041
5	.032	.029	.041	.025	.040	.033
6	.029	.027	.033	.024	.034	.029
Average	.071	.069	.077	.066	.076	.072

LINCOLN.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.241	.245	.234	.238	.242	.240
2	.122	.145	.124	.122	.133	.129
3	.068	.073	.072	.063	.072	.070
4	.050	.060	.058	.065	.065	.060
5	.045	.047	.043	.040	.036	.042
6	.054	.046	.042	.039	.036	.043
Average	.097	.103	.095	.094	.097	.097

WEEPING WATER.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.228	.232	.242	.243	.237	.236
2	.149	.149	.146	.171	.153	.154
3	.081	.086	.080	.097	.070	.083
4	.053	.053	.052	.073	.064	.059
5	.047	.043	.041	.044	.041	.043
6	.040	.039	.035	.039	.039	.038
Average	.100	.100	.099	.111	.101	.102

TABLE XIX.

NITROGEN IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
Foot	%	%	%	%	%	%	%
1	.136	.139	.182	.174	.240	.236	.185
2	.082	.084	.101	.098	.129	.154	.108
3	.065	.054	.065	.057	.070	.083	.066
4	.046	.038	.045	.041	.060	.059	.048
5	.038	.032	.034	.033	.042	.043	.037
6	.030	.030	.034	.029	.043	.038	.034
Average	.066	.063	.077	.072	.097	.102	.079

soil tending to accumulate less organic matter. However, a comparison of the hygroscopic coefficients for the first foot of the McCook and Hastings fields, makes it evident that the texture does not account for the differences between these in nitrogen; at McCook the hygroscopic coefficient averages higher, while the five fields in that area are lower in nitrogen than those at Hastings. The greater amount of nitrogen is probably due to the greater production of vegetable material, both as aerial portions and as roots, in the eastern areas, which in turn is a consequence of the greater rainfall and lower evaporation.

TABLE XX.

AVERAGE NITROGEN CONTENT OF THE FIRST SIX FEET OF EACH FIELD IN EACH OF THE SIX AREAS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.063	.062	.070	.071	.097	.100
II	.065	.070	.075	.069	.103	.100
III	.075	.062	.080	.077	.095	.099
IV	.066	.063	.082	.066	.094	.111
V	.063	.059	.076	.076	.097	.101
Average	.066	.063	.077	.072	.097	.102

From Table XXI it may be seen that in the first foot the nitrogen in all fields is highest in the first inch, while the amount in the twelfth is approximately half of that in the first.

A fair comparison of the nitrogen content of two fields is difficult, for the reason that if the soil of one is the more compact, the sampling tools will penetrate relatively deeper and as a result the soil sample will show a lower nitrogen content. For this reason, instead of taking the samples that are to be under comparison to the same depth, they should be taken so as to secure the same dry weight of each in a section with the same surface.

To determine the influence of such differences in density upon the found nitrogen content we weighed the samples from all the fields of each of the areas, except the two first sampled—Lincoln and Holdrege. In none of the twenty fields did we find any relation between depth and

TABLE XXI.

NITROGEN IN THE INCH SECTIONS FROM THE SURFACE FOOT OF THE FIVE FIELDS OF EACH AREA.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
			WAUNETA.			
1	.219	.202	.224	.184	.197	.205
2	.192	.183	.169	.151	.169	.173
3	.177	.170	.162	.145	.173	.165
4	.161	.146	.159	.130	.150	.149
5	.145	.131	.140	.114	.142	.134
6	.138	.120	.132	.112	.136	.128
7	.128	.114	.124	.103	.121	.118
8	.120	.108	.117	.103	.114	.112
9	.122	.109	.116	.102	.115	.113
10	.113	.100	.107	.095	.106	.104
11	.105	.093	.103	.088	.102	.098
12	.101	.088	.099	.087	.099	.095
Average	.143	.130	.138	.118	.135	.132
			McCOOK.			
1	.220	.208	.205	.212	.174	.204
2	.157	.184	.169	.165	.151	.165
3	.158	.173	.164	.165	.155	.163
4	.167	.163	.162	.157	.145	.159
5	.153	.150	.145	.148	.133	.146
6	.144	.145	.135	.140	.133	.139
7	.128	.132	.129	.127	.122	.128
8	.115	.120	.119	.116	.109	.116
9	.113	.116	.113	.109	.100	.110
10	.099	.112	.106	.099	.093	.102
11	.094	.104	.097	.096	.087	.096
12	.094	.101	.090	.090	.086	.092
Average	.137	.142	.136	.135	.124	.135
			HOLDREGE.			
1	.238	.391	.361	.318	.305	.323
2	.213	.286	.282	.261	.291	.267
3	.204	.259	.246	.221	.239	.234
4	.182	.229	.206	.200	.215	.206
5	.167	.204	.188	.179	.196	.187
6	.161	.180	.168	.167	.173	.170
7	.139	.172	.158	.155	.158	.156
8	.137	.153	.144	.147	.149	.146
9	.132	.152	.140	.141	.145	.142
10	.122	.142	.134	.135	.141	.135
11	.124	.134	.136	.132	.137	.133
12	.115	.131	.130	.127	.132	.127
Average	.161	.203	.191	.182	.190	.186

TABLE XXI.—(Continued).

HASTINGS.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.287	.312	.350	.409	.411	.354
2	.216	.235	.259	.235	.241	.237
3	.196	.203	.219	.206	.200	.205
4	.182	.184	.195	.185	.181	.186
5	.170	.176	.183	.175	.169	.175
6	.159	.164	.168	.166	.154	.162
7	.154	.161	.165	.156	.146	.156
8	.149	.155	.158	.148	.138	.150
9	.142	.147	.150	.147	.135	.144
10	.140	.142	.145	.143	.130	.140
11	.136	.138	.142	.141	.127	.137
12	.131	.134	.138	.137	.122	.132
Average	.172	.179	.189	.187	.180	.181

LINCOLN.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.495	.296	.293	.304	.348	.347
2	.327	.273	.254	.253	.287	.279
3	.299	.255	.235	.240	.265	.259
4	.275	.250	.224	.231	.248	.245
5	.262	.241	.212	.223	.231	.234
6	.253	.229	.205	.211	.215	.223
7	.224	.221	.195	.205	.205	.210
8	.219	.214	.186	.192	.196	.201
9	.217	.202	.176	.184	.184	.193
10	.202	.186	.167	.175	.173	.181
11	.197	.177	.160	.163	.166	.173
12	.185	.168	.148	.159	.154	.163
Average	.260	.226	.205	.212	.223	.225

WEEPING WATER.

Depth Inch	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
1	.310	.281	.481	.290	.345	.341
2	.267	.266	.390	.275	.288	.297
3	.250	.248	.273	.259	.269	.260
4	.237	.235	.249	.246	.253	.244
5	.225	.230	.235	.237	.240	.233
6	.218	.219	.226	.232	.231	.225
7	.211	.213	.221	.225	.214	.217
8	.202	.209	.212	.215	.204	.208
9	.200	.201	.205	.210	.199	.203
10	.198	.199	.195	.207	.193	.198
11	.190	.185	.186	.203	.187	.190
12	.181	.183	.181	.197	.185	.185
Average	.224	.222	.255	.233	.234	.234

density farther than that, as a rule, the first and second inch sections were lighter than the deeper ones. If the average weight of the 1-3 inch section in the 20 fields be placed at 100, the average weights for the 4-6, 7-9 and 10-12 inch sections would become 111, 110 and 111, respectively. The surface foot of the eastern fields is somewhat denser than that of the western, the relative averages being: Wauneta 94, McCook 90, Hastings

TABLE XXII.

NITROGEN IN THE INCH SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth Inch	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	.205	.204	.323	.354	.347	.341	.296
2	.173	.165	.267	.237	.279	.297	.236
3	.165	.163	.234	.205	.259	.260	.214
4	.149	.159	.206	.186	.246	.244	.198
5	.134	.146	.187	.175	.234	.233	.185
6	.128	.139	.170	.162	.223	.225	.175
7	.118	.128	.156	.156	.210	.217	.164
8	.112	.118	.146	.150	.201	.208	.156
9	.113	.110	.142	.144	.193	.203	.151
10	.104	.102	.135	.140	.181	.198	.143
11	.098	.096	.133	.137	.173	.190	.138
12	.095	.092	.127	.132	.163	.185	.132
Average	.132	.135	.186	.181	.225	.234	.182

110, and Weeping Water 108 (Table XXIII). The greater density of the samples from the eastern fields may be due to differences in moisture content at the time of sampling, the soil of the western areas being dry and that of the eastern more or less moist. In the case of all the Wauneta and McCook fields, of II and V at Hastings, and II, III and V at Weeping Water, samples for moisture determination were taken at the same time as those for chemical analysis. In the first foot of all the fields of the western areas the free water, the difference between the total moisture and the hygroscopic coefficient, lay between 0.0 and 2.0 per cent, while in the five eastern fields mentioned it was 13.4, 9.5, 14.4, 6.8 and 11.6 per cent respectively. When moist the soil tends to permit of a greater compression as the sampling tube is forced in. The difference to be observed among the ten western fields could not have been influenced by the moisture content as this was similar in all. At Hastings all five fields were sampled within less than five days of one another during a period of fair weather following a succession of rains. At Weeping Water the fields were sampled near the end of November, after two months of almost rainless weather; here a difference of 100 per cent in the free water content was not accompanied by a distinct difference in the found density. It may be that the density of the surface foot of the western prairies is less than that of the eastern, but we do not consider our data sufficient to justify any such definite conclusion.

The depth of sampling should vary inversely as the found density. If the depths indicated in Table XXIV had been employed, the average dry weight of the twenty cores from each field used in the preparation of the inch samples would have been practically the same. From the data in Tables XXI and XXIV we can calculate the per cent of nitrogen in the first foot that would have been found if such a method of sampling had been followed. The extent to which they differ from the averages of the twelve sections given in Table XXI is shown in Table XXV. While in general the difference is not great it is evident that in any fine work the relative weights of the samples under comparison should not be ignored. The importance of this has previously been pointed out (4, 2). It is readily apparent that the soil of a pasture field may be expected to show a greater density than that of a meadow, and, consequently, if both are sampled to the same depth, also a lower nitrogen content, although the two may be equally rich in this constituent.

TABLE XXIII.

RELATIVE DENSITY OF THE SURFACE FOOT OF SOIL FROM DIFFERENT FIELDS. (AVERAGE OF THE 20 = 100.)

Field No.	Wauneta	McCook	Hastings	Weeping Water
I	93	102	88	101
II	99	98	125	110
III	90	81	127	111
IV	95	83	95	111
V	92	87	115	107
Average	94	90	110	108

TABLE XXIV.

DEPTH IN INCHES TO WHICH THE DIFFERENT FIELDS SHOULD HAVE BEEN SAMPLED IN ORDER TO SECURE THE SAME WEIGHT OF SOIL FROM EACH.

Field No.	Wauneta	McCook	Hastings	Weeping Water
I	10.5	9.5	11.0	9.5
II	10.0	10.0	8.0	9.0
III	11.0	12.0	7.5	9.0
IV	10.5	11.5	10.5	9.0
V	11.0	11.0	8.5	9.0

The differences above are quite similar to those shown between the nitrogen content of the composite of 10 individual samples taken with an auger and that secured by the tube from the same field (Table XXVI).

TABLE XXV.

CHANGE IN THE NITROGEN CONTENT FOUND FOR THE FIRST FOOT THAT WOULD HAVE BEEN CAUSED BY USING THE SAME WEIGHT, INSTEAD OF THE SAME DEPTH OF SOIL.

Field No.	Wauneta	McCook	Hastings	Weeping Water
I	.005	.011	.004	.009
II	.008	.008	.019	.010
III	.003	.000	.025	.021
IV	.004	.002	.007	.010
V	.003	.011	.021	.016

TABLE XXVI.

DIFFERENCES IN NITROGEN CONTENT FOUND IN THE TWO SETS OF SAMPLES FROM THE SAME FIELD. A DEFICIENCY FOR THE AVERAGE OF THE INCH SECTIONS IS INDICATED BY THE MINUS SIGN.

Field No. No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.006	—.006	—.011	.001	.019	—.004
II	—.007	—.004	.029	.005	—.019	—.010
III	—.007	—.002	.027	.006	—.029	.013
IV	—.011	—.008	—.007	.018	—.026	—.010
V	.003	—.001	—.019	.006	—.019	—.001

Organic Carbon.

The organic carbon was determined by combustion with copper oxide in a current of oxygen, the 10-gram sample of soil having first been treated with phosphoric acid solution and evaporated to dryness. It was found desirable in the case of the calcareous subsoils to repeat the treatment with phosphoric acid in order to ensure the full decomposition of carbonates. Analyses were made of all the field foot-samples (Table XXVII), the averages of which give the data for the area foot-samples (Table XXVIII), and also of the area inch-samples (Table XXIX). The average carbon content for the six foot-sections from each field is given in Table XXX.

In all the areas the carbon decreases from the surface downward, both in the foot and in the inch sections. As was the case with the nitrogen content, the fields may be placed in three groups according to the amount of carbon in the surface foot. The Wauneta and McCook fields have between 1.49 and 1.81 per cent, the Holdrege and Hastings fields between 1.93 and 2.50, and those of the eastern two areas between 2.76 and 3.07. On the basis of the composition of the second foot only two distinct groups, as with the nitrogen, are recognizable. For the third, fourth, fifth and sixth feet there is no grouping, the highest average content being shown by the two outer groups, that for the four feet for Weeping Water being .44 per cent against .42 for Wauneta and that for the fourth to sixth foot being .35 and .32 per cent, respectively. The fields of the two eastern areas show the same relative differences in the carbon as in the nitrogen content, they being similar in the first but those at Lincoln having, with one exception, a distinctly smaller amount in the second foot.

Again, as with nitrogen, the differences are not so regular when we consider the average for the six feet of the different fields (Table XXX), the distinction between the western and the central areas disappearing.

The rate of decrease in the carbon content from the first to the twelfth inch in the surface foot is quite similar in all the areas.

TABLE XXVII.
ORGANIC CARBON IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

Depth Foot	Field I %	Field II %	Field III %	Field IV %	Field V %	Average %
WAUNETA.						
1	1.67	1.64	1.70	1.54	1.49	1.61
2	.83	.75	.91	.77	.73	.80
3	.55	.65	.67	.77	.50	.63
4	.38	.59	.51	.45	.36	.46
5	.29	.28	.50	.25	.30	.32
6	.24	.21	.46	.18	.22	.26
Average	.66	.69	.79	.66	.60	.68
McCOOK.						
1	1.63	1.81	1.66	1.72	1.41	1.65
2	.71	.92	.77	.88	.70	.80
3	.42	.72	.53	.55	.58	.56
4	.32	.45	.32	.29	.31	.34
5	.25	.35	.27	.22	.33	.28
6	.23	.22	.22	.19	.20	.21
Average	.59	.74	.63	.64	.59	.64
HOLDREGE.						
1	2.10	2.16	2.24	2.32	2.50	2.26
2	.93	1.05	1.22	1.10	1.11	1.08
3	.49	.56	.75	.69	.50	.60
4	.33	.36	.46	.47	.27	.38
5	.21	.29	.29	.21	.21	.24
6	.21	.23	.26	.19	.15	.21
Average	.71	.78	.87	.83	.79	.79
HASTINGS.						
1	2.02	1.97	2.19	1.93	2.19	2.06
2	1.04	1.01	1.14	.93	1.13	1.05
3	.64	.56	.56	.44	.67	.57
4	.36	.32	.35	.21	.42	.33
5	.23	.20	.29	.14	.33	.24
6	.16	.15	.20	.14	.25	.18
Average	.74	.70	.79	.63	.83	.74
LINCOLN.						
1	2.87	2.88	2.77	2.88	2.98	2.88
2	1.32	1.32	1.19	1.31	1.46	1.32
3	.66	.62	.61	.63	.77	.66
4	.34	.36	.34	.31	.38	.35
5	.22	.25	.28	.23	.27	.25
6	.19	.23	.22	.25	.24	.23
Average	.93	.94	.90	.94	1.02	.95
WEEPING WATER.						
1	2.82	2.76	2.95	3.07	2.85	2.89
2	1.76	1.74	1.43	2.07	1.75	1.75
3	.80	.73	.59	1.02	.87	.80
4	.47	.48	.45	.56	.44	.48
5	.27	.27	.23	.30	.25	.26
6	.24	.22	.16	.24	.20	.21
Average	1.06	1.03	.97	1.21	1.06	1.06

TABLE XXVIII.

ORGANIC CARBON IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	1.61	1.65	2.26	2.06	2.88	2.89	2.22
2	.80	.80	1.08	1.05	1.32	1.75	1.14
3	.63	.56	.60	.57	.66	.80	.64
4	.46	.34	.38	.33	.35	.48	.39
5	.32	.28	.24	.24	.25	.26	.26
6	.26	.21	.21	.18	.23	.21	.22
Average	.68	.64	.79	.74	.95	1.06	.81

TABLE XXIX.

ORGANIC CARBON IN THE DIFFERENT INCH SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth Inch	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	2.85	2.42	4.60	4.52	4.70	4.52	3.93
2	2.11	1.94	3.50	3.17	3.65	3.71	3.01
3	1.85	1.90	2.87	2.58	3.31	3.25	2.63
4	1.67	1.82	2.45	2.28	3.12	3.07	2.40
5	1.48	1.65	2.17	2.03	2.84	2.83	2.17
6	1.46	1.54	2.01	1.86	2.74	2.65	2.04
7	1.31	1.44	1.77	1.79	2.50	2.37	1.86
8	1.27	1.34	1.72	1.67	2.39	2.34	1.79
9	1.23	1.26	1.62	1.59	2.31	2.29	1.72
10	1.14	1.16	1.55	1.53	2.08	2.18	1.61
11	1.03	1.07	1.49	1.52	1.97	2.14	1.54
12	1.03	1.00	1.45	1.45	1.89	2.09	1.48
Average	1.54	1.54	2.25	2.17	2.79	2.79	2.18

TABLE XXX.

AVERAGE CONTENT OF ORGANIC CARBON IN THE FIRST SIX FEET OF EACH FIELD IN EACH OF THE SIX AREAS.

Field No.	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %
I	.66	.59	.71	.74	.93	1.06
II	.69	.74	.78	.70	.94	1.03
III	.79	.63	.87	.79	.90	.97
IV	.66	.64	.83	.63	.94	1.21
V	.60	.59	.79	.83	1.02	1.06
Average	.68	.64	.80	.74	.95	1.07

CARBON-NITROGEN RATIO.

The ratio of the organic carbon to the nitrogen shows some interesting differences. In the surface foot the ratio is everywhere very similar, it varying only between 11.2 and 13.6 for the field samples (Table XXXI). It is independent of the aridity. In the second foot it is lower than in the surface foot, and while it shows a tendency to be lower in the western than in the eastern areas this is not an area characteristic as may be seen from the data for the individual fields. While in most cases the third foot shows a lower ratio than the second, and the fourth one still lower, in neither is an area characteristic exhibited. In the fifth and sixth feet the ratio is still lower, it decreasing less in general in the western areas. As a result of this an accurate analysis of samples from the western, central and eastern areas might be expected to show characteristic differences regularly when the samples analyzed were composites of a very large number of individual samples.

Even in the surface foot the differences in the Carbon-Nitrogen ratio are small (Table XXXIII). It decreases from a maximum varying from 11.9 to 14.3 in the surface inch to a minimum of 10.4 to 11.4 in the twelfth.

VOLATILE MATTER AND WATER OF CONSTITUTION.

The *volatile matter* as ordinarily determined (6, p. 14) is reported in Table XXXIV together with the organic matter (organic C × 1.724) and the so-called "water of constitution," which represents the difference between the two preceding values. Instead of the abitrary 1.724, probably different factors should be used for the different depths; also, judging from the Carbon-Nitrogen ratio, it should not be considered as a constant for even the same depth of subsoil in different fields. However, as nothing more serviceable is as yet available the same factor has been used throughout in calculating the organic matter from the organic carbon. The found percentage of "water of constitution," which in this case represents the water not expelled at 110° C but driven off below a dull red heat, will be affected by any inaccuracy in the determination of organic carbon. As it is derived chiefly from the hydrated silicates and oxides it may be expected to vary as the sum of the alumina and the iron oxide. Considering the average of the six foot depths, it is seen to increase slightly from west to east and in each area to show a maximum in the second or third foot.

The variations are closely concordant with those of the hygroscopicity (Table XXXV). The average ratio of hygroscopic coefficient to water of constitution is 3.43. This ratio varies only between 3.27 and 3.65 for areas, and between 3.40 and 3.53 for the different levels.

TABLE XXXI.

RATIO OF ORGANIC CARBON TO NITROGEN IN THE FOOT SECTIONS FROM THE FIVE FIELDS OF EACH AREA.

WAUNETA.

Depth Ft.	Field I	Field II	Field III	Field IV	Field V	Average
1	12.4	11.9	11.8	12.0	11.3	11.9
2	10.4	9.6	9.9	9.4	9.3	9.7
3	9.3	11.2	9.3	9.8	8.3	9.6
4	8.9	10.5	12.1	9.6	8.4	9.9
5	8.8	8.0	10.2	6.4	8.4	8.4
6	8.6	8.4	9.4	7.8	8.1	8.5
Average	9.7	9.9	10.5	9.2	9.0	9.7

McCOOK.

1	11.4	12.4	12.0	12.0	11.3	11.8
2	9.0	10.2	9.7	10.0	8.3	9.4
3	8.8	10.7	10.2	10.6	10.7	10.2
4	8.9	8.2	8.7	8.1	9.1	8.6
5	8.1	9.5	8.0	7.6	10.6	8.8
6	6.9	7.1	7.3	6.6	7.4	7.1
Average	8.8	9.7	9.3	9.1	9.6	9.3

HOLDREGE.

1	12.2	12.4	13.6	12.3	12.0	12.5
2	10.4	10.7	10.9	10.6	10.7	10.7
3	8.9	8.8	10.1	9.2	9.1	9.2
4	8.7	8.4	8.7	8.4	7.3	8.3
5	6.8	7.6	7.2	6.5	7.7	7.2
6	6.2	6.8	6.7	5.6	4.4	6.0
Average	8.9	9.1	9.5	8.8	8.5	9.0

HASTINGS.

1	11.8	11.3	11.9	11.4	12.6	11.8
2	11.0	10.6	11.2	10.0	10.8	10.7
3	10.8	10.2	9.0	8.2	11.3	9.9
4	8.4	8.2	8.0	6.6	9.1	8.1
5	7.2	6.9	7.1	5.6	8.3	7.0
6	5.5	5.6	6.1	5.8	7.3	6.1
Average	9.1	8.8	8.9	7.9	9.9	8.9

LINCOLN.

1	11.9	11.8	11.8	12.1	12.3	12.0
2	10.8	9.1	9.6	10.7	11.0	10.2
3	9.7	8.5	8.5	10.0	10.7	9.5
4	6.7	6.0	5.9	4.8	5.9	5.9
5	4.9	5.3	6.5	5.8	7.5	6.0
6	3.5	5.0	5.2	6.4	6.7	5.4
Average	7.9	7.6	7.9	8.3	9.0	8.2

WEEPING WATER.

1	12.3	11.9	12.2	12.6	12.0	12.2
2	11.8	11.7	9.8	12.1	11.4	11.4
3	9.9	8.5	7.4	10.5	12.4	9.5
4	8.9	9.1	8.6	7.7	6.9	8.2
5	5.7	6.3	5.6	6.8	6.1	6.1
6	6.0	5.7	4.6	6.4	5.1	5.6
Average	9.1	8.9	8.0	9.3	9.0	8.8

TABLE XXXII.

RATIO OF ORGANIC CARBON TO NITROGEN IN THE DIFFERENT FOOT SECTIONS OF THE SIX DIFFERENT AREAS.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	11.9	11.8	12.5	11.8	12.0	12.2	12.0
2	9.7	9.4	10.7	10.7	10.2	11.4	10.3
3	9.6	10.2	9.2	9.9	9.5	9.5	9.6
4	9.9	8.6	8.3	8.1	5.9	8.2	8.2
5	8.4	8.8	7.2	7.0	6.0	6.1	7.6
6	8.5	7.1	6.0	6.1	5.4	5.6	6.6
Average	9.7	9.3	9.0	8.9	8.2	8.8	9.1

TABLE XXXIII.

RATIO OF ORGANIC CARBON TO NITROGEN IN THE DIFFERENT FOOT SECTIONS OF THE SURFACE FOOT OF THE SIX DIFFERENT AREAS.

Depth In.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	14.3	11.9	14.3	12.8	13.8	13.3	13.4
2	12.2	11.8	13.1	13.4	13.1	12.5	12.8
3	11.2	11.7	12.3	12.6	12.8	12.5	12.3
4	11.2	11.5	11.9	12.3	12.7	12.5	12.0
5	11.0	11.3	11.6	11.6	12.1	12.1	11.6
6	11.4	11.1	11.8	11.5	12.3	11.8	11.6
7	11.1	11.3	11.3	11.5	11.9	10.9	11.3
8	11.3	11.4	11.8	11.1	11.9	11.3	11.5
9	10.9	11.5	11.4	11.0	12.0	11.2	11.3
10	11.0	11.3	11.5	10.9	11.5	11.5	11.3
11	10.5	10.9	11.1	11.1	11.4	11.3	11.0
12	10.6	10.4	11.4	11.0	11.6	11.3	11.0
Average	11.4	11.3	12.0	11.7	12.3	11.9	11.8

Comparison With Chernozem Soils.

The soils of the transition region are, in comparison with the typical Russian Chernozem soils, low in both organic matter and nitrogen. In the surface 4 to 8 inches of the latter, where it has formed upon loess, the organic carbon varies from 3.5 to 6.0 per cent (20, p. 318) and the nitrogen from 0.3 to 0.5 per cent. Both are highest in the central portion of the Chernozem zone and decrease with the approach on one side to the forest regions and on the other to the desert areas. Where the soils have not long been under cultivation these constituents decrease with the depth more or less regularly, although at some distance from the surface there is a rather sharp break, the rate of increase being accelerated.

The two series of analyses from the government of Saratof, given in Table XXVI (20, p. 322) may serve to illustrate the difference in both amount and manner of distribution of the organic matter compared with

TABLE XXXXIV.

VOLATILE MATTER, ORGANIC MATTER AND WATER OF CONSTITUTION IN THE FOOT SECTIONS FROM THE DIFFERENT AREAS.

VOLATILE MATTER.

Depth Foot	Wauneta %	McCook %	Holdrege %	Hastings %	Lincoln %	Wpg.Wtr. %	Average %
1	5.05	5.71	7.10	6.25	8.44	8.43	6.83
2	4.03	4.52	5.10	5.45	6.68	7.17	5.49
3	4.08	3.74	4.48	4.63	5.25	5.24	4.57
4	3.47	3.44	3.98	4.00	4.22	4.46	3.93
5	2.75	3.28	3.34	3.83	4.07	4.27	3.59
6	2.97	3.00	3.10	3.71	3.90	3.99	3.44
Average	3.72	3.97	4.52	4.64	5.43	5.59	4.64

ORGANIC MATTER (C X 1.724).

1	2.77	2.85	3.90	3.55	4.96	4.98	3.83
2	1.38	1.44	1.86	1.81	2.28	3.02	1.96
3	1.09	.97	1.01	.98	1.14	1.38	1.09
4	.79	.59	.66	.60	.60	.83	.68
5	.55	.48	.41	.41	.43	.45	.45
6	.45	.36	.36	.31	.40	.36	.37
Average	1.17	1.11	1.37	1.28	1.63	1.84	1.40

WATER OF CONSTITUTION.

1	2.28	2.86	3.20	2.70	3.48	3.45	2.99
2	2.65	3.08	3.24	3.64	4.40	4.15	3.53
3	2.99	2.77	3.47	3.65	4.11	3.86	3.48
4	2.68	2.85	3.32	3.40	3.62	3.63	3.24
5	2.20	2.80	2.93	3.42	3.64	3.82	3.14
6	2.52	2.64	2.74	3.40	3.50	3.63	3.07
Average	2.55	2.83	3.15	3.37	3.79	3.76	3.24

TABLE XXXV.

RATIO OF HYGROSCOPIC COEFFICIENT TO WATER OF CONSTITUTION.

Depth Ft.	Wauneta	McCook	Holdrege	Hastings	Lincoln	Wpg.Wtr.	Average
1	3.99	3.50	3.16	3.55	3.45	3.51	3.53
2	3.62	3.54	3.46	3.19	3.27	3.30	3.40
3	3.24	3.77	3.26	3.40	3.31	3.60	3.43
4	3.69	3.40	3.00	3.26	3.59	3.58	3.42
5	4.09	3.25	3.28	3.13	3.52	3.30	3.43
6	3.29	3.45	3.43	3.15	3.63	3.44	3.40
Average	3.65	3.49	3.27	3.28	3.46	3.45	3.43

that in the transition soils. The rate of decrease is similar, but at corresponding depths the amounts are much lower in the latter. The organic carbon[1] in the first four inches of the Weeping Water and Lincoln areas is barely above the lower limit (3.5 per cent) mentioned above.

The carbon and nitrogen in the Chernozem soils rise and fall together, the ratio being generally somewhat below 11.6 for the surface soil and decreasing from the surface downward (20, p. 323). As this value is based largely upon the analyses of long cultivated soils in which the ratio is perceptibly lower than in virgin soils (3_2, p. 137; 5, p. 161) it is to be regarded as showing no distinct difference from that in the transition soils.

TABLE XXXVI.

COMPARISON OF THE DISTRIBUTION OF ORGANIC CARBON IN CHERNOZEM SOILS WITH THAT IN THE NEBRASKA LOESS SOILS.

Depth	Chernozem Soils from		Transition Soils from	
	Serdobsk %	Atkarsk %	Weeping Water %	Wauneta %
0-2 inches	7.07	....	4.11	2.48
2-4 inches	....	6.50	3.16	1.76
4-6 inches	6.60	....	2.74	1.47
6-8 inches	....	6.50	2.35	1.29
8-10 inches	4.54	4.58	2.24	1.18
2nd foot	3.56	3.66	1.75	.80
3rd foot	2.00	2.08	.80	.63
4th foot	1.03	.80	.48	.46

Unfortunately data from systematic fertilizer experiments on the Nebraska loess are not available, but such as there are, those from scattered trials in cooperation with farmers, leave it an open question whether phosphate fertilizers will at present cause any distinct crop increase. However, there appears no doubt that applications of nitrogen fertilizers would increase crop yields, the inadequacy of the supply of available nitrogen in the eastern areas appearing within 20 or 30 years at the most. In this respect the transition soils appear to differ much from the Russian Chernozem soils, which, as mentioned above (p. 202), long retain their fertility, and, when this declines, show a lack first of phosphoric acid, and only later of nitrogen.

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[1] The percentages of organic carbon in the Chernozem soils mentioned in this section have been calculated from the "humus" reported by Kossowitsch, who, like all continental Europeans, employs the term as synonymous with our "organic matter of the soil," determined by combustion with copper oxide. In the United States the term *humus* is commonly used to signify only the alkali-soluble portion, although a few Americans use it to signify the whole of the organic matter. Thus Cameron speaks of "the introduction of humus by a grass crop or a green manure crop." (The Soil Solution, 1911, p. 4.)

[2] In Table IV in the reference the carbon in the soil "in cultivation 21 years, in grass 4 years," was, through typographical error reported as 2.10 per cent instead of 3.10.

COMPARISON WITH ARID SOILS.

It would be of interest to compare the soils of the different areas, and especially those of the two western semi-arid ones, with the arid soils of the United States, but data on the organic carbon and nitrogen content of the latter are rather too scanty to permit of any satisfactory comparison, Hilgard's and Loughridge's extended studies reporting the humus and the humus-nitrogen instead of the organic matter and the total nitrogen.

However, we have data on the relative "rawness" of the subsoils of all the areas. Hilgard has repeatedly called attention to the lack of this in arid subsoils; "cellars and house foundations are dug, and the material removed, even to the depth of 8 feet, is fearlessly put on the garden and there serves as a new soil on which vegetables and small fruits grow, the first year, as well as ever" (18, p. 166). Still more recently (19, p. 418) he writes: "Such a heap now lying before my eyes,[1] the upper layer of which had eight months before been excavated from a depth of 4 meters and still retained the last rain, shows a thick stand of *grasses*[2] and weeds of all kinds, among them wild oats, radish, mustard, ..."[3]

We have found, both from pot experiments and by observation in different parts of the loess region where considerable areas of subsoil had been deeply exposed by railroad excavations, that inoculated legumes grow almost as well on the subsoils from depths of 3 to 20 feet as on the corresponding black surface soil, but that non-leguminous plants fail to make any satisfactory growth unless treated with a nitrogen fertilizer or preceded by legume crops. The subsoils of the eastern areas appear no more "raw" than do those of the extreme western. Thus in this respect the semi-arid soils, instead of showing a behavior intermediate between that of the arid soils and that of the humid loess soils, strictly resemble the latter.

SUMMARY.

The soils studied represent the first six foot-sections, and also the twelve one-inch sections of the surface foot, from five virgin prairie fields in each of six so-called "areas" in Nebraska, located between the Missouri River and the western limit of the loess, a distance of more than 300 miles, in which, while the temperature conditions, wind velocity and relative humidity, are quite uniform, there is a great range in aridity, the annual precipitation decreasing from more than 30 inches in the east to less

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[1] In Berkeley, California.

[2] Italics by the author and not in the original article.

[3] Author's translation from Hilgard, loc. cit.

than 20 in the west, while the relative aridity exhibits a still greater range on account of the increase in the rate of evaporation which accompanies the decrease in precipitation.

The hygroscopicity, as expressed by the hygroscopic coefficient, is strikingly uniform both from field to field in any one area and from the surface downward in the same field. It is lowest in the two western areas and highest in the two eastern. When the different levels from the individual fields are compared, the highest is found in either the second or the third foot, in which two it is very similar. The minimum value is found in the surface foot of the three eastern areas, and in the sixth of the three western. The uniformity within any area is so great that in estimating the free moisture in the first six feet of soil of any field, provided that it be loess, it appears satisfactory to employ simply the average hygroscopic coefficient for all the fields of the area. The effect of the organic matter upon the hygroscopicity is too slight to be detected, a change of even 100 per cent in the content of this being without distinct influence.

The nitrogen content in all the fields decreases from the surface downward. In the surface foot, in which it was determined in each of the twelve inch sections, it decreases steadily, there being in general about half as much in the twelfth as in the first inch section. The nitrogen in the surface foot decreases by about 50 per cent as we pass from the most easterly to the most westerly fields, the difference being such as to permit a definite grouping of the areas. The most easterly areas show as high a content in the second foot as do the most westerly in the first. In this level also there is a decrease from east to west, but it does not show the gradual change exhibited in the first foot. In the still lower levels, third to sixth foot, although the nitrogen in general is higher in the eastern than in the western fields, the differences are small.

The great difference in density of the surface soil from field to field combined with the rapid decrease in nitrogen from the surface downward in virgin prairies, renders satisfactory sampling difficult, which should be carried out in such a way that in sections of like surface equal weights of dry soil are secured.

The organic carbon in the surface foot is very similar in distribution to that of the nitrogen. The amount of the former is approximately 12 times that of the latter, the ratio being uninfluenced by the aridity of the climate. When the inch sections of the surface foot are considered it is seen that the organic carbon decreases slightly more rapidly than does the nitrogen, the average ratio being 13.4 for the first, and 11.3 for the twelfth inch section. In the levels below the first foot also a similar difference in the rate of decrease is observed, the ratio in some cases falling as low as 6.0. The decrease is less rapid in the western than in the eastern areas, the average organic carbon content in the fourth, fifth, and sixth feet being higher in the two most westerly areas than in the two most easterly, while that of the nitrogen is lower.

The decrease in nitrogen and organic carbon in the surface soil as we proceed from east to west cannot be explained by the increase in coarseness of texture, but must be attributed to the greater vegetative growth without a correspondingly more rapid decay in the eastern areas.

The water of constitution—the difference between volatile matter and organic matter—decreases from east to west, the variations being concordant with those in the hygroscopicity.

Compared with the Russian Chernozem soils formed on loess the organic carbon and the nitrogen are low both in the surface soil and in the subsoil, the amounts found in the eastern areas being similar to the minima reported for the Chernozem.

The subsoils from the semi-arid areas, in so far as the nitrogen is concerned, in contrast with the arid subsoils, are as "raw" as those from the humid areas, not supporting a satisfactory growth of non-leguminous plants.

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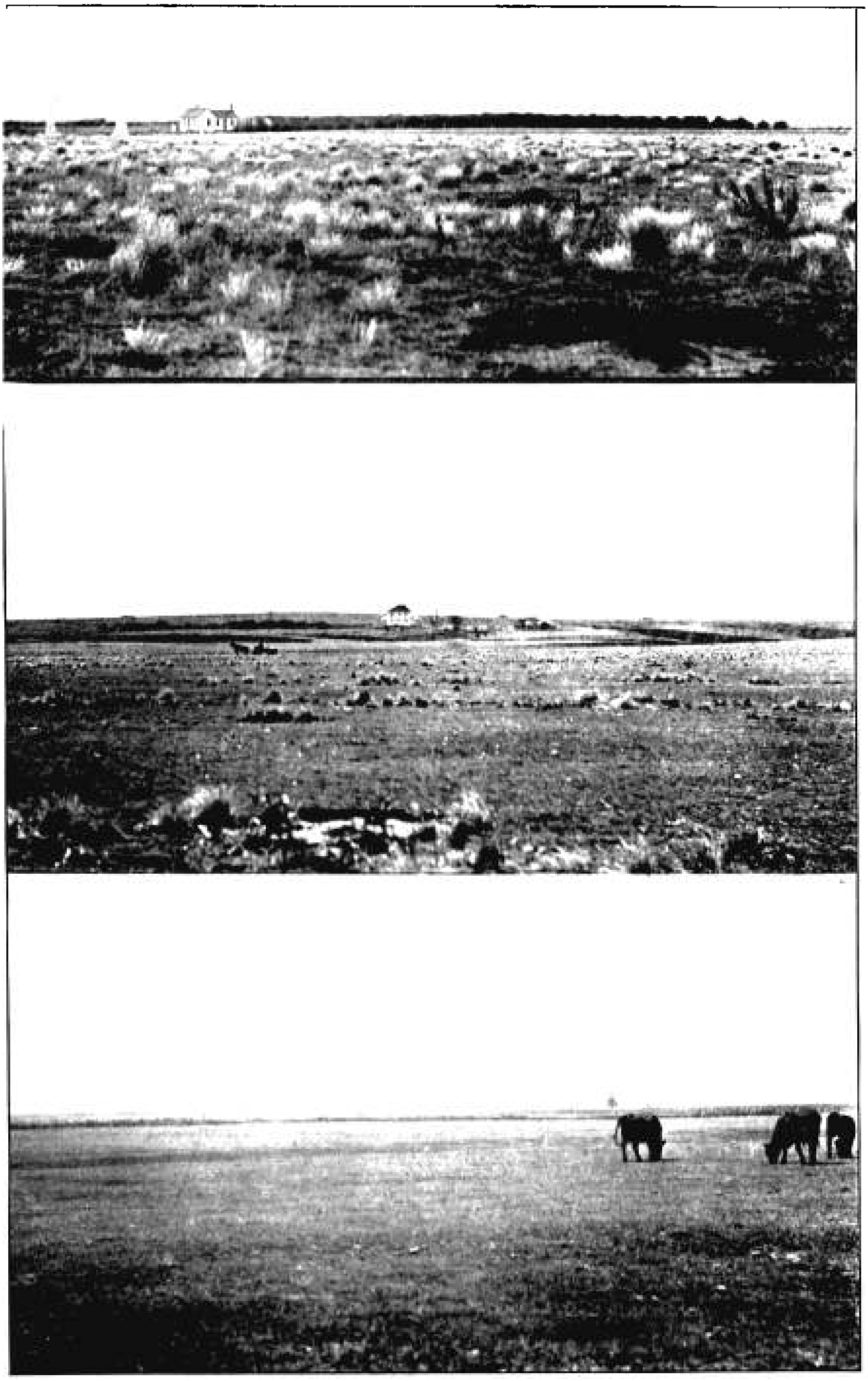
PLATE I.

Fig. 1.—Field II at Wauneta showing very level character of fields in this area. A young orchard is shown in the foreground.

Fig. 2.—Field III at McCook. Planted trees about the farmstead. Canyons in the loess at the right.

Fig. 3.—Field V at Holdredge, showing level topography. Planted trees in the distance.



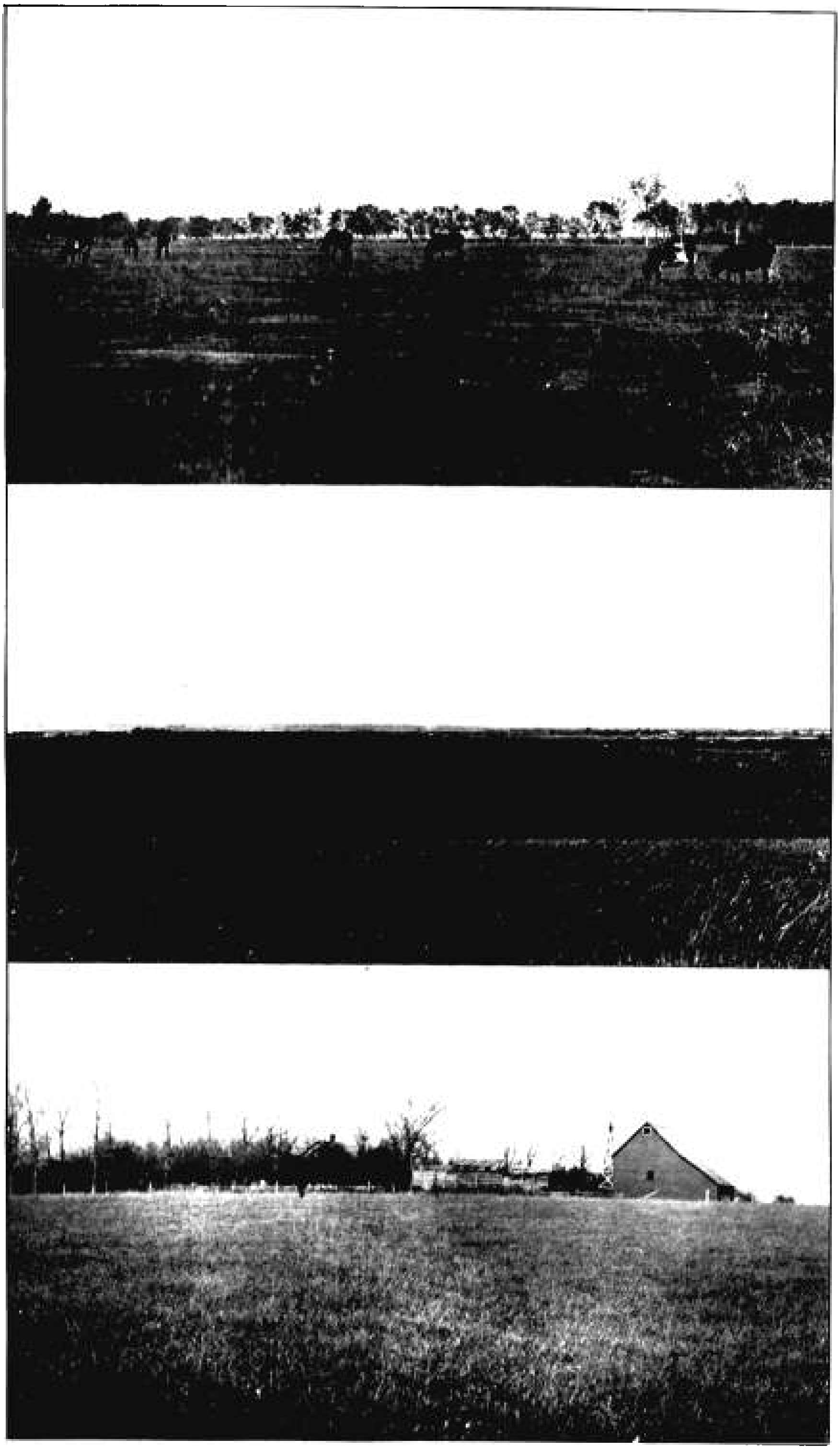


PLATE II.

Fig. 1.—Field IV at Hastings, showing very level topography. Planted trees in the distance.

Fig. 2.—Field IV at Lincoln, showing rolling topography and, in the distance, native trees along water-courses.

Fig. 3.—Field V at Weeping Water, showing orchard and shade trees about a farmstead. This was one of the very few comparatively level tracts that had not been brought under the plow.

PLATE III.

Fig. 1.—At the western edge of the loess plain. Looking westward from Field IV at Wauneta, showing the lower-lying plain of Tertiary rocks covered with residual soil. The loess extends about 300 yards beyond the immediate foreground.

Fig. 2.—A canyon in the loess between Fields II and IV at Wauneta, showing contact of loess with underlying unaltered Tertiary rock. The man is shown standing on a slight projection of the latter. The photograph was taken from the opposite side of the canyon.